US009130151B2

(12) **United States Patent**
Butler

(10) **Patent No.:** **US 9,130,151 B2**
(45) **Date of Patent:** **Sep. 8, 2015**

(54) **METHOD AND SYSTEM FOR PROVIDING MAGNETIC TUNNELING JUNCTIONS USABLE IN SPIN TRANSFER TORQUE MAGNETIC MEMORIES**

(75) Inventor: **William H. Butler**, Tuscaloosa, AL (US)

(73) Assignee: **SAMSUNG ELECTRONICS CO., LTD.**, Gyeonggi-Do (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 439 days.

(21) Appl. No.: **13/549,331**

(22) Filed: **Jul. 13, 2012**

(65) **Prior Publication Data**

US 2012/0326253 A1 Dec. 27, 2012

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/685,418, filed on Jan. 11, 2010, now Pat. No. 8,254,162.

(51) **Int. Cl.**

G11C 11/00	(2006.01)
H01L 43/08	(2006.01)
B82Y 25/00	(2011.01)
B82Y 40/00	(2011.01)
H01F 10/32	(2006.01)
H01F 41/30	(2006.01)
H01L 43/12	(2006.01)
G11C 11/16	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H01L 43/08*** (2013.01); ***B82Y 20/00*** (2013.01); ***B82Y 25/00*** (2013.01); ***B82Y 40/00*** (2013.01); ***G11C 11/161*** (2013.01); ***H01F 10/329*** (2013.01); ***H01F 10/3254*** (2013.01); ***H01F 10/3286*** (2013.01); ***H01F 41/307*** (2013.01); ***H01F 41/325*** (2013.01); ***H01L 43/12*** (2013.01); *H01F 10/123* (2013.01); *H01L 27/228* (2013.01)

(58) **Field of Classification Search**

USPC 365/48, 55, 62, 66, 74, 78, 80–93, 100, 365/130, 131, 148, 158, 171–173, 209, 213, 365/225.5, 230.07, 232, 243.5; 257/295, 257/421, 422, 427, E21.665, E27.006; 438/3; 977/933–935

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,020,000	A	2/2000	Wong
6,532,164	B2	3/2003	Redon

(Continued)

OTHER PUBLICATIONS

Office Action issued Apr. 2008 for U.S. Appl. No. 11/239,969.

(Continued)

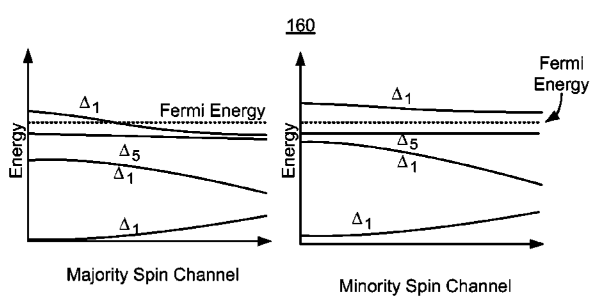
Primary Examiner — Harry W Byrne

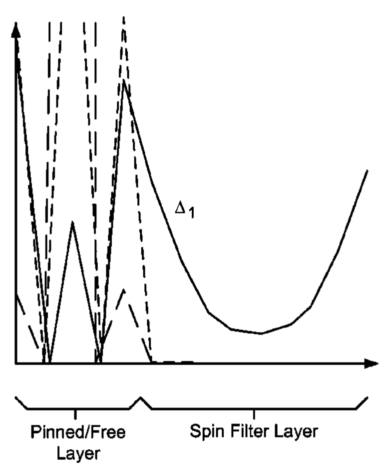
(74) *Attorney, Agent, or Firm* — Convergent Law Group LLP

(57) **ABSTRACT**

A method and system provide a magnetic junction. A free layer, a symmetry filter, and a pinned layer are provided. The free layer has a magnetic moment switchable between stable states when a write current is passed through the magnetic junction. The symmetry filter transmits charge carriers having a first symmetry with higher probability than charge carriers having another symmetry. The symmetry filter resides between the free layer and the pinned layer. The free layer and/or the pinned layer lies in a plane, has the charge carriers of the first symmetry in a spin channel at a Fermi level, lacks the charge carriers of the first symmetry at the Fermi level in another spin channel, and has a nonzero magnetic moment component perpendicular to the plane. The free layer and/or the pinned layer and the symmetry filter has at least one lattice mismatch of less than seven percent.

16 Claims, 7 Drawing Sheets





(51) **Int. Cl.**

B82Y 20/00	(2011.01)
H01F 41/32	(2006.01)
H01L 27/22	(2006.01)
H01F 10/12	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,611,405	B1	8/2003	Inomata	
6,771,534	B2	8/2004	Stipe	
6,967,863	B2	11/2005	Huai	
7,061,797	B1 *	6/2006	Miltat et al.	365/171
7,101,600	B1	9/2006	Kim	
7,106,624	B2	9/2006	Huai et al.	
7,241,631	B2	7/2007	Huai	
7,598,555	B1	10/2009	Parkin	
7,630,234	B2	12/2009	Sugibayshi	
7,826,258	B2	11/2010	Zhu	
2002/0105827	A1	8/2002	Redon	
2003/0007398	A1	1/2003	Daughton	
2003/0059588	A1	3/2003	Hannah	
2003/0227807	A1	12/2003	Nakamura	
2004/0012994	A1 *	1/2004	Slaughter et al.	365/158
2004/0125647	A1	7/2004	Tsuchida	
2005/0040433	A1	2/2005	Nozieres	
2005/0042367	A1	2/2005	Nemoto	
2005/0104101	A1	5/2005	Sun	
2005/0106810	A1 *	5/2005	Pakala et al.	438/257
2005/0174702	A1	8/2005	Gill	
2006/0017083	A1 *	1/2006	Slaughter et al.	257/295
2006/0087880	A1 *	4/2006	Mancoff et al.	365/158
2007/0091670	A1	4/2007	Hidaka	
2008/0007992	A1	1/2008	Wang	
2008/0026253	A1	1/2008	Yuasa	
2008/0246104	A1	10/2008	Ranjan	

OTHER PUBLICATIONS

Office Action issued Sep. 2008 for U.S. Appl. No. 11/239,969.

Office Action issued Jan. 2010 for U.S. Appl. No. 12/133,671.

Office Action issued Apr. 2009 for U.S. Appl. No. 12/133,671.

Office Action issued Mar. 2011 for U.S. Appl. No. 12/638,902.

IOP Publishing, Science and Technology of Advanced Materials 9, William H. Butler, Tunneling Magnetoresistance From a Symmetry Filtering Effect, pp. 1-17, Apr. 21, 2008.

Japanese abstract of publication No. 11-120758, Apr. 30, 1999, Non-volatile Random Access Memory, Eric Maiken.

Albert, et al., "Polarized Current Switching of a CO Thin Film Nanomagnet," American Institute of Physics, 77(23): 3809-11, 2000.

Berger, "Emission of spin waves by a magnetic multilayer traversed by a current," Physical Review B, 54(13), 9953-58, 1996.

Butler, et al., "Spin Dependent Tunneling Conductance of Fe/MgO/Fe Sandwiches," Physical Review B, 63: 092409, 2001.

Ideda, et al., "A perpendicular anisotrophy COFeB—MgO magnetic tunnel junction," Nature Materials Online, Jul. 11, 2010, DOI:10.1038/NMAT2804.

Katine, et al., "Current-Driven Magnetization Reversal and Spin-Wave Excitations in CO/Cu/Co Pillars," Physical Review Letters, 84(14): 3149-52, 2000.

Myers, "Point-contact studies of current-controlled domain switching in magnetic multilayers," Journal of Applied Physics, vol. 87-No. 9, May 1, 2000, pp. 5502-5503.

Nishimura, et al., "Magnetic tunnel junction device with perpendicular magnetization films for high-density magnetic random access memory," Journal of Applied Physics, 90(8): 5246-49, 2002.

Parkin, et al., "Giant tunneling magnetoresistance at room temperature with MgO (100) tunnel barriers," Nature Materials 3:862-7, 2004.

Slonczewski, "Conductance and exchange coupling of two ferromagnets separated by a tunneling barrier," Physical Review B, 39(10): 6995-7002, 1989.

Sloczewski, "Current-driven excitation of magnetic multilayers," Journal of Magnetism and Magnetic Materials, 159: L1-L7, 1996.

Slonczewski, "Theory and Application of Exchange-Driven Switching," IEEE, pp. CE-02, 2000.

Sun, "Current-driven magnetic switching in manganite trilayer junctions," Journal of Magnetism and Magnetic Materials, No. 202, 1999, pp. 157-162.

Zhang, "Large magnetoresistance in bcc Co/MgO/Co and FeCo/MgO/FeCo tunneling junctions," Physics Review B 70: 172407, 2004.

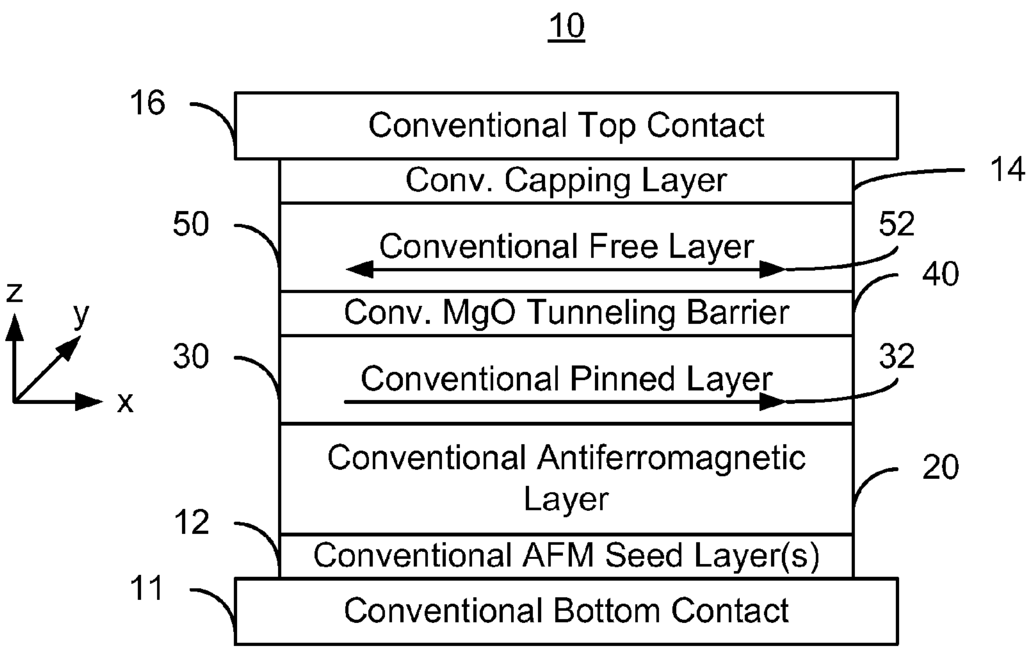
PCT International Search Report and Written Opinion of the ISA, application No. PCT/US08/64794.

PCT International Search Report and Written Opinion of the ISA, application No. PCT/US08/66369.

PCT International Search Report and Written Opinion of the ISA, application No. PCT/US10/47941.

PCT International Search Report and Written Opinion of the ISA, application No. PCT/US10/59184.

* cited by examiner



Prior Art
FIG. 1

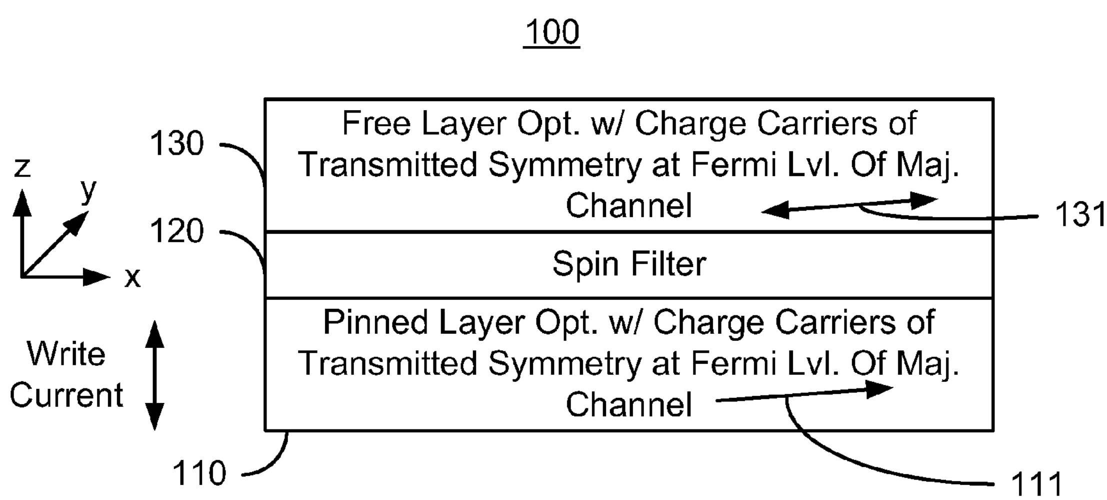


FIG. 2

160

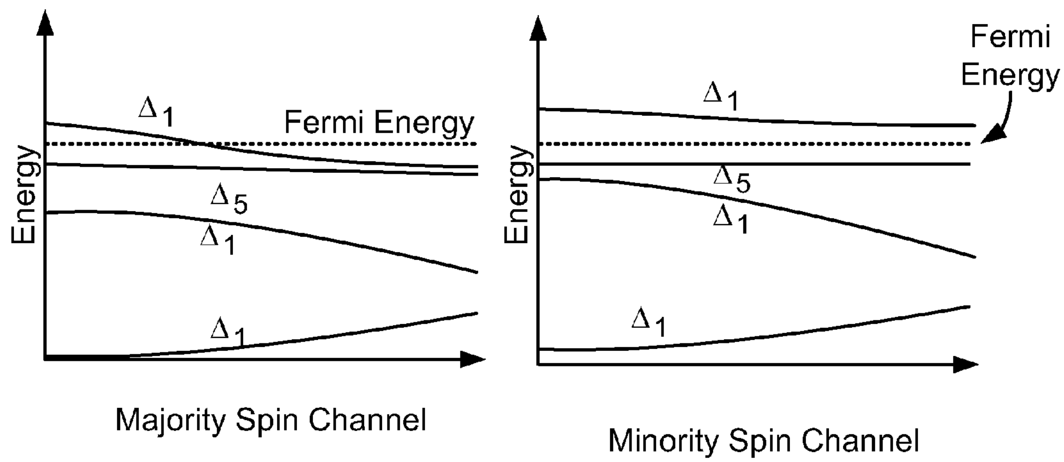


FIG. 3

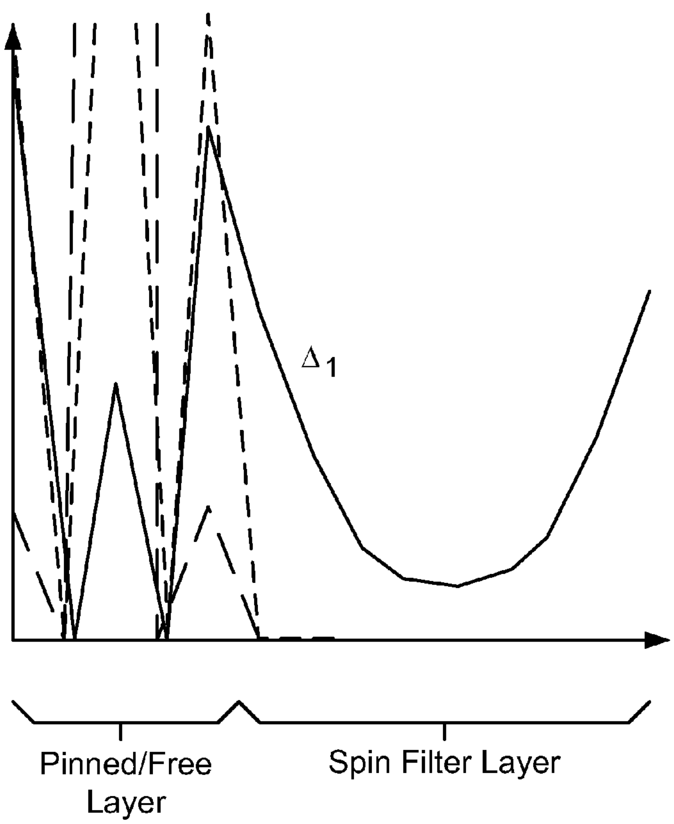


FIG. 4

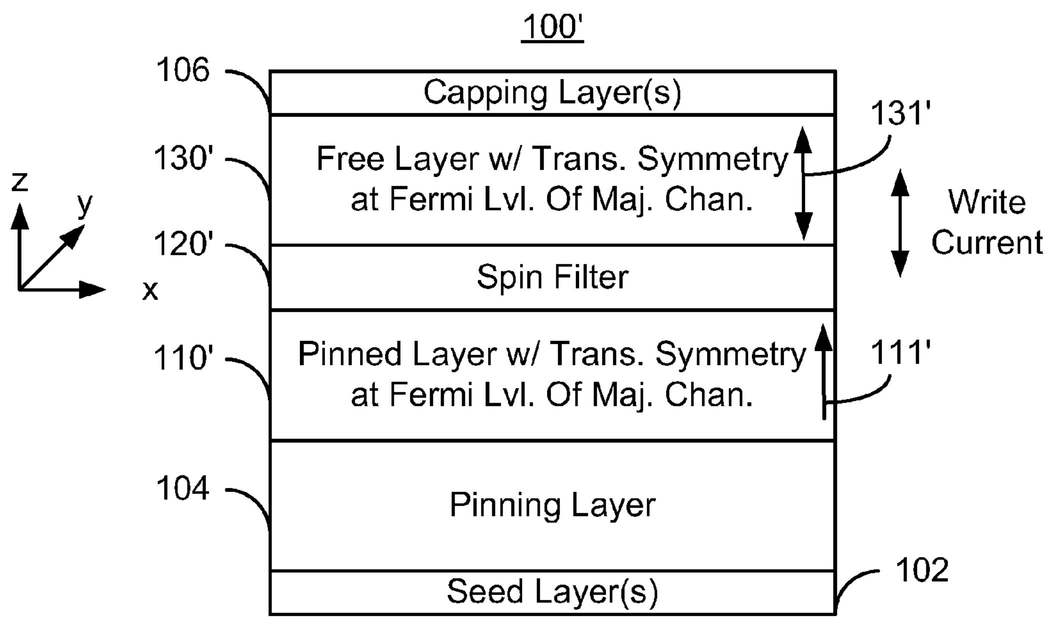

100'
106
Capping Layer(s)
130'
Free Layer w/ Trans. Symmetry at Fermi Lvl. Of Maj. Chan.
131'
Write Current
z
y
x
120'
Spin Filter
110'
Pinned Layer w/ Trans. Symmetry at Fermi Lvl. Of Maj. Chan.
111'
104
Pinning Layer
Seed Layer(s)
102

FIG. 5

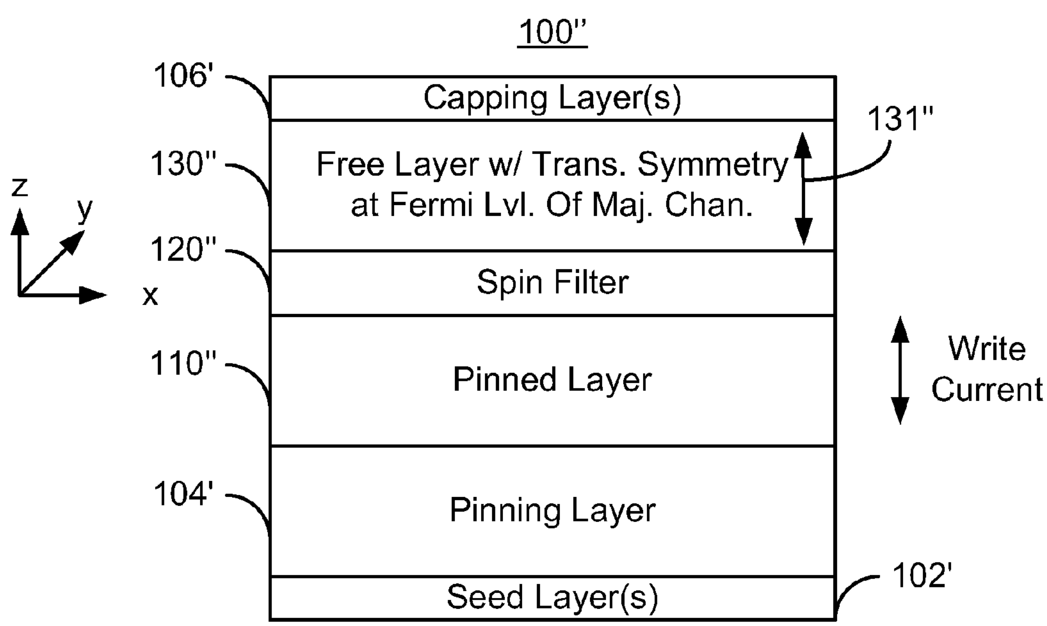

100''
106'
Capping Layer(s)
130''
Free Layer w/ Trans. Symmetry at Fermi Lvl. Of Maj. Chan.
131''
z
y
x
120''
Spin Filter
110''
Pinned Layer
Write Current
104'
Pinning Layer
Seed Layer(s)
102'

FIG. 6

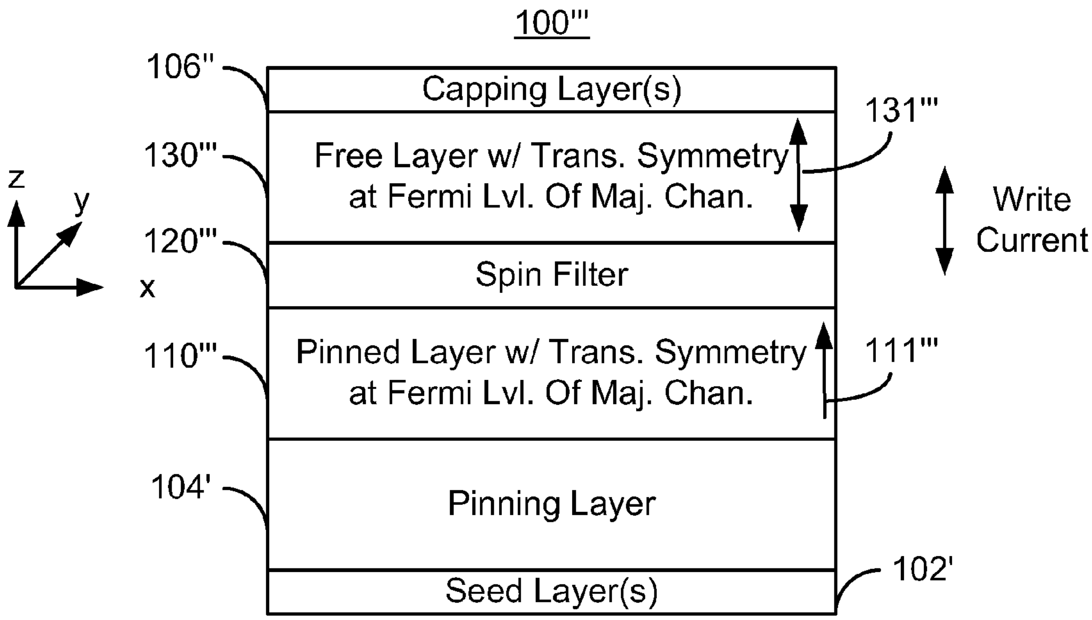

100'''
106''
Capping Layer(s)
130'''
Free Layer w/ Trans. Symmetry at Fermi Lvl. Of Maj. Chan.
131'''
Write Current
z
y
x
120'''
Spin Filter
110'''
Pinned Layer w/ Trans. Symmetry at Fermi Lvl. Of Maj. Chan.
111'''
104'
Pinning Layer
Seed Layer(s)
102'

FIG. 7

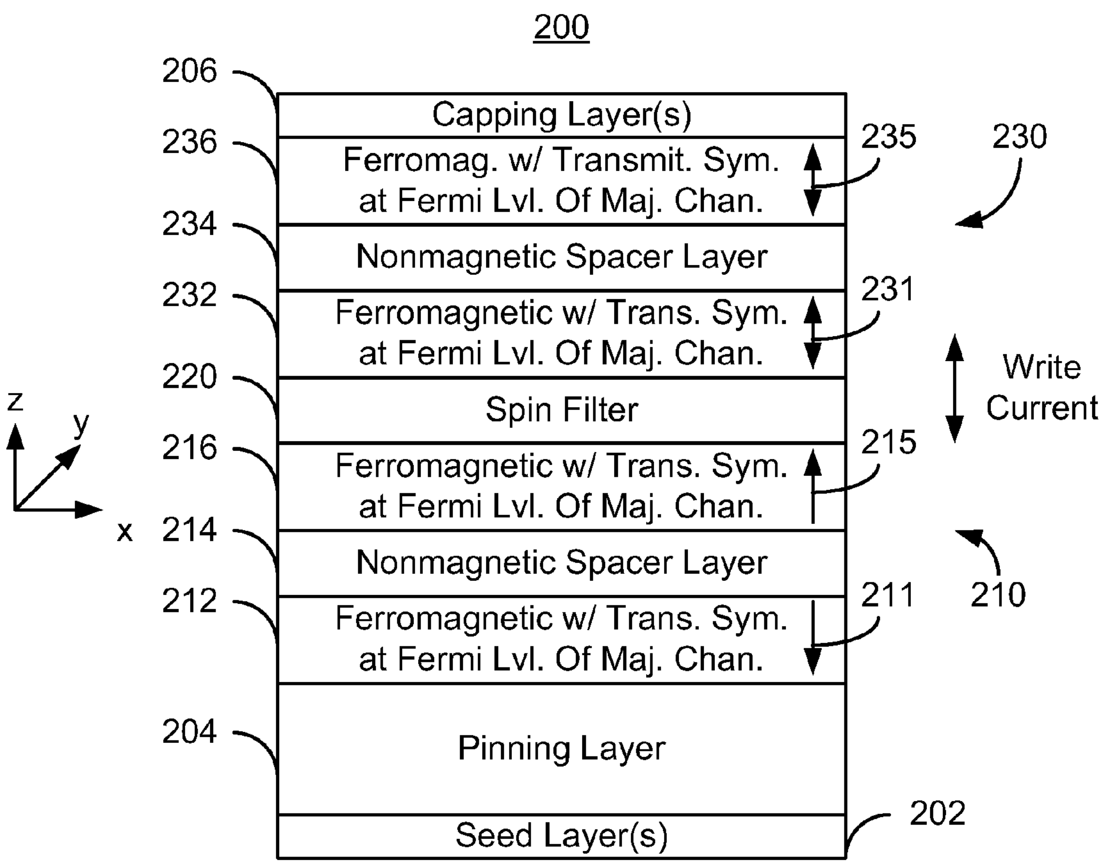

200
206
Capping Layer(s)
236
Ferromag. w/ Transmit. Sym. at Fermi Lvl. Of Maj. Chan.
235
230
234
Nonmagnetic Spacer Layer
232
Ferromagnetic w/ Trans. Sym. at Fermi Lvl. Of Maj. Chan.
231
220
Spin Filter
Write Current
z
y
x
216
Ferromagnetic w/ Trans. Sym. at Fermi Lvl. Of Maj. Chan.
215
214
Nonmagnetic Spacer Layer
210
212
Ferromagnetic w/ Trans. Sym. at Fermi Lvl. Of Maj. Chan.
211
204
Pinning Layer
Seed Layer(s)
202

FIG. 8

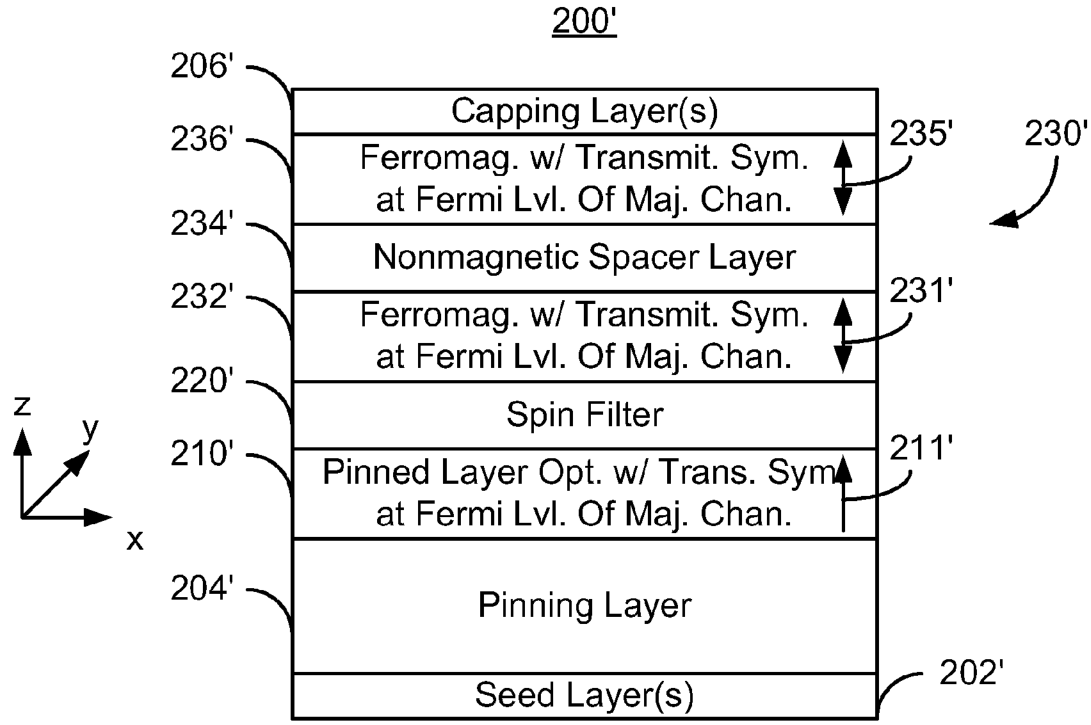

200'
206'
Capping Layer(s)
236'
Ferromag. w/ Transmit. Sym. at Fermi Lvl. Of Maj. Chan.
235'
230'
234'
Nonmagnetic Spacer Layer
232'
Ferromag. w/ Transmit. Sym. at Fermi Lvl. Of Maj. Chan.
231'
220'
Spin Filter
z
y
x
210'
Pinned Layer Opt. w/ Trans. Sym. at Fermi Lvl. Of Maj. Chan.
211'
204'
Pinning Layer
Seed Layer(s)
202'

FIG. 9

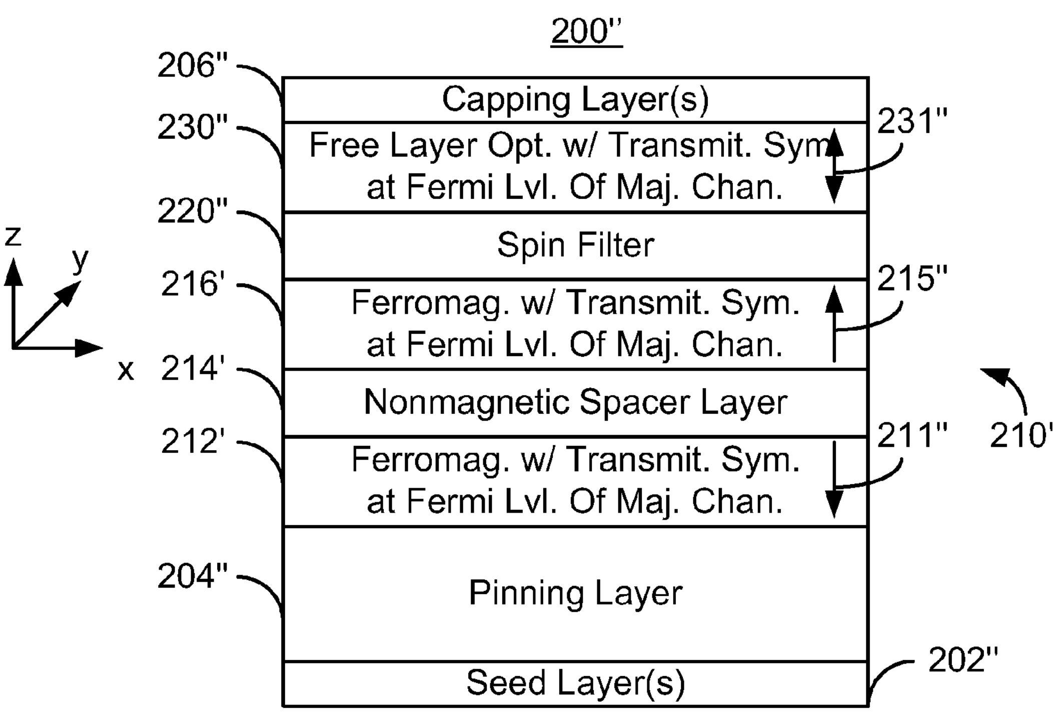

200''
206''
Capping Layer(s)
230''
Free Layer Opt. w/ Transmit. Sym. at Fermi Lvl. Of Maj. Chan.
231''
220''
Spin Filter
z
y
x
216'
Ferromag. w/ Transmit. Sym. at Fermi Lvl. Of Maj. Chan.
215''
214'
Nonmagnetic Spacer Layer
210''
212'
Ferromag. w/ Transmit. Sym. at Fermi Lvl. Of Maj. Chan.
211''
204''
Pinning Layer
Seed Layer(s)
202''

FIG. 10

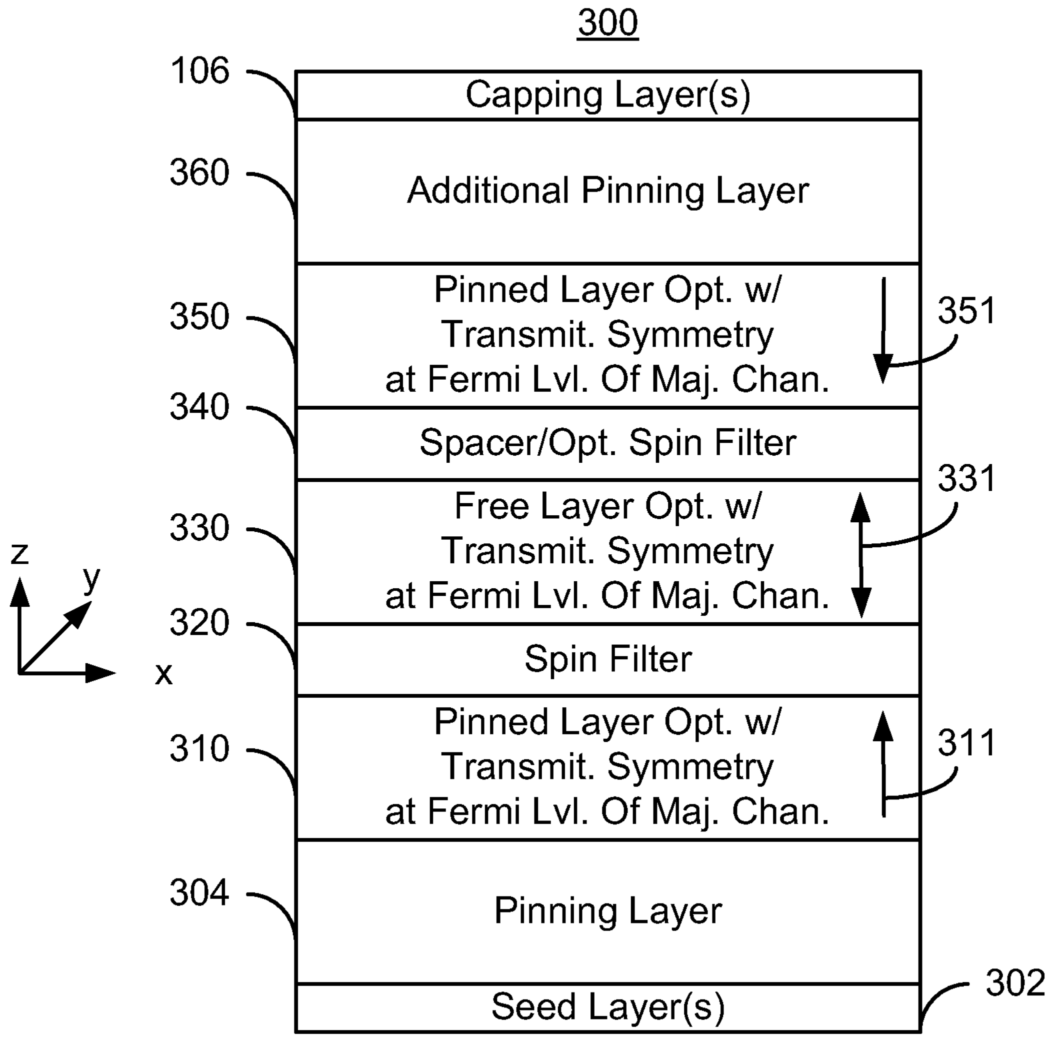

300
106
Capping Layer(s)
360
Additional Pinning Layer
350
Pinned Layer Opt. w/ Transmit. Symmetry at Fermi Lvl. Of Maj. Chan.
351
340
Spacer/Opt. Spin Filter
331
330
Free Layer Opt. w/ Transmit. Symmetry at Fermi Lvl. Of Maj. Chan.
320
Spin Filter
310
Pinned Layer Opt. w/ Transmit. Symmetry at Fermi Lvl. Of Maj. Chan.
311
304
Pinning Layer
302
Seed Layer(s)
z
y
x

FIG. 11

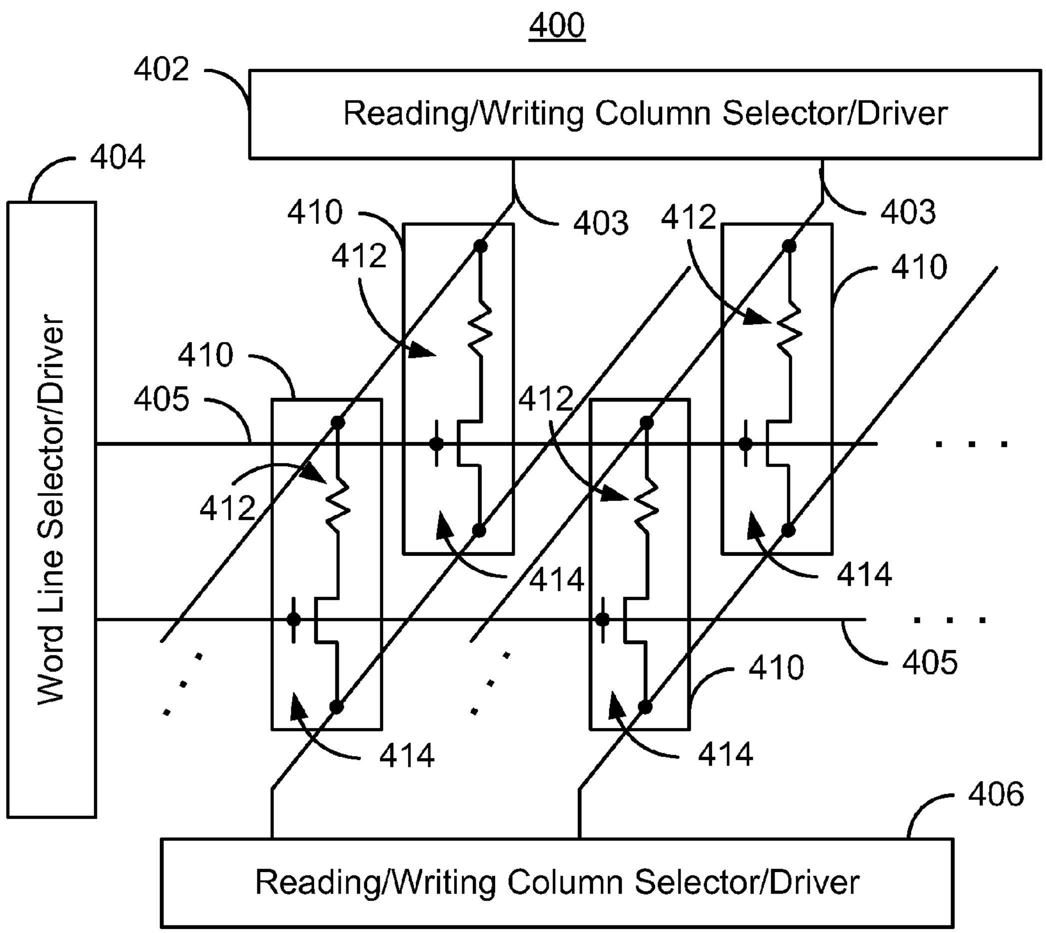

400
402
Reading/Writing Column Selector/Driver
404
403
410
412
403
412
403
410
Word Line Selector/Driver
410
405
412
412
414
414
410
405
414
414
406
Reading/Writing Column Selector/Driver

FIG. 12

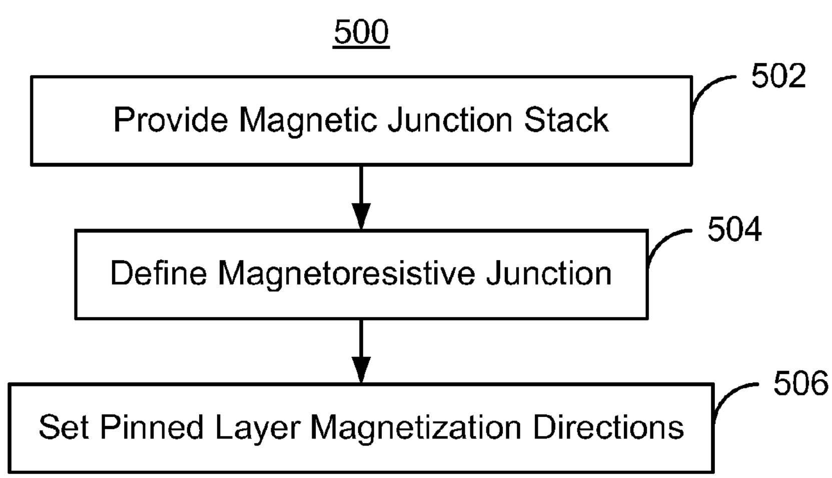

500
Provide Magnetic Junction Stack
502
Define Magnetoresistive Junction
504
Set Pinned Layer Magnetization Directions
506

FIG. 13

METHOD AND SYSTEM FOR PROVIDING MAGNETIC TUNNELING JUNCTIONS USABLE IN SPIN TRANSFER TORQUE MAGNETIC MEMORIES

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of co-pending patent application Ser. No. 12/685,418, filed Jan. 11, 2010, entitled "Method and System for Providing Magnetic Tunneling Junctions Usable in Spin Transfer Torque Magnetic Memories", and assigned to the assignee of the present application.

GOVERNMENT RIGHTS

This invention was made with U.S. Government support under Grant/Contract No. HR0011-09-C-0023 awarded by DARPA. The U.S. Government retains certain rights in this invention. Distribution authorized to U.S. Government Agencies only.

BACKGROUND OF THE INVENTION

Magnetic memories, particularly magnetic random access memories (MRAMs), have drawn increasing interest due to their potential for high read/write speed, endurance, non-volatility and low power consumption during operation. One type of MRAM is a spin transfer torque random access memory (STT-RAM). STT-RAM utilizes magnetic junctions written at least in part by a current driven through the magnetic junction.

FIG. **1** depicts a conventional magnetic tunneling junction (MTJ) **10** as it may be used in a conventional STT-RAM. The conventional MTJ **10** typically resides on a bottom contact **11**, uses conventional seed layer(s) **12** and is under a top contact **16**. The conventional MTJ **10** includes a conventional antiferromagnetic (AFM) layer **20**, a conventional pinned layer **30**, a conventional tunneling barrier layer **40**, and a conventional free layer **50**. Also shown is a conventional capping layer **14**. The conventional free layer **50** has a changeable magnetic moment **52**, while the magnetic moment **43** of the conventional pinned layer **30** is stable. More specifically, the magnetic moment **32** of the conventional pinned layer **30** is fixed by an interaction with the conventional AFM layer **20**.

Conventional contacts **12** and **16** are used in driving the current in a current-perpendicular-to-plane (CPP) direction, or along the z-axis as shown in FIG. **1**. Current passing through the conventional pinned layer **30** becomes spin polarized and carries angular momentum. This angular momentum may be transferred to the conventional free layer **50**. If a sufficient amount of angular momentum is so transferred, the magnetic moment **52** of the free layer **50** may be switched to be parallel or antiparallel to the magnetic moment **32** of the pinned layer **30**.

To improve the performance of STT-RAM, various factors of the conventional magnetic junction **10** are desired to be optimized. For example, the conventional magnetic junction **10** may be engineered for a desired critical current, I_c, for switching a thermally stable conventional free layer **50**. The critical current may be estimated by:

$$I_c = \frac{\alpha}{\eta}\frac{\langle H\rangle_{eff}}{H_K}1.5\text{ mA}$$

where $\langle H\rangle_{eff}$ is the averaged effective magnetic field seen by the precessing magnetic moments of the conventional free layer **50**, H_k is the magnetic field necessary to switch the magnetic moment **52** when applied along the easy axis, α is the damping parameter, η is the spin-torque efficiency, and 1.5 mA represents current and is appropriate to a thermal stability factor ($\Delta E/k_BT$) of 60, where ΔE represents the energy barrier for thermal switching, k_B is Boltzmann's constant and T is the absolute temperature.

The conventional magnetic junction **10** may be optimized to improve the critical current. Engineering the conventional magnetic junction **10** may include use of CoFe and/or CoFeB for the conventional pinned layer **30** and the conventional free layer **50**. CoFe and CoFeB tend to have in-plane magnetic moments, as shown by the magnetic moments **32** and **52**. In addition, the conventional tunneling barrier **40** is typically crystalline MgO. The combination of CoFe and CoFeB with MgO may result in a lower critical current.

Although the conventional magnetic tunneling junction **10** functions, further improvements are desired. For example, magnetic junctions usable in magnetic memories that may be smaller, scalable to smaller dimensions, use a lower critical current, may be simple to fabricate, and/or have other properties are desired.

Accordingly, what is desired is an improved magnetic junction usable in higher density STT-RAM.

BRIEF SUMMARY OF THE INVENTION

A method and system for providing a magnetic junction are described. The method and system includes providing a free layer, a symmetry filter, and a pinned layer. The free layer has a first magnetic moment switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction. The symmetry filter transmits charge carriers having a first symmetry with higher probability than charge carriers having another symmetry. The pinned layer has a second magnetic moment pinned in a particular direction. The symmetry filter resides between the free layer and the pinned layer. At least one of the free layer and the pinned layer has the charge carriers of the first symmetry in a spin channel at the Fermi level, lacks the charge carriers of the first symmetry at the Fermi level in another spin channel, lies in a plane, and has a nonzero magnetic moment component substantially perpendicular to plane. The free layer and/or the pinned layer and the symmetry filter has at least one lattice mismatch of less than seven percent. In some aspects, the symmetry filter includes at least one of Ge, GaAs and ZnSe.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** depicts a conventional magnetic tunneling junction.

FIG. **2** depicts an exemplary embodiment of a magnetic junction suitable for use in a magnetic memory.

FIG. **3** depicts an exemplary embodiment of the band structures for the majority and minority spin channels in the free and/or pinned layer(s) of the exemplary embodiment of the magnetic junction.

FIG. **4** depicts an exemplary embodiment of transmission of charge carriers through a symmetry filter based upon wave function symmetry.

FIG. 5 depicts another exemplary embodiment of a magnetic junction suitable for use in a magnetic memory in which both the free layer and the pinned layer have a state at the Fermi energy with a symmetry that is preferentially transmitted by the spin filter layer.

FIG. 6 depicts another exemplary embodiment of a magnetic junction suitable for use in a magnetic memory.

FIG. 7 depicts another exemplary embodiment of a magnetic junction suitable for use in a magnetic memory.

FIG. 8 depicts another exemplary embodiment of a magnetic junction suitable for use in a magnetic memory.

FIG. 9 depicts another exemplary embodiment of a magnetic junction suitable for use in a magnetic memory.

FIG. 10 depicts another exemplary embodiment of a magnetic junction suitable for use in a magnetic memory.

FIG. 11 depicts another exemplary embodiment of a dual magnetic junction suitable for use in a magnetic memory.

FIG. 12 depicts an exemplary embodiment of a magnetic memory utilizing a magnetic junction.

FIG. 13 depicts an exemplary embodiment of a method for fabricating a magnetic tunneling junction suitable for use in a magnetic memory.

DETAILED DESCRIPTION OF THE INVENTION

The exemplary embodiments relate to magnetic junctions usable in magnetic devices, such as magnetic memories, and the devices using such magnetic junctions. The following description is presented to enable one of ordinary skill in the art to make and use the invention and is provided in the context of a patent application and its requirements. Various modifications to the exemplary embodiments and the generic principles and features described herein will be readily apparent. The exemplary embodiments are mainly described in terms of particular methods and systems provided in particular implementations. However, the methods and systems will operate effectively in other implementations. Phrases such as “exemplary embodiment”, “one embodiment” and “another embodiment” may refer to the same or different embodiments as well as to multiple embodiments. The embodiments will be described with respect to systems and/or devices having certain components. However, the systems and/or devices may include more or less components than those shown, and variations in the arrangement and type of the components may be made without departing from the scope of the invention. The exemplary embodiments will also be described in the context of particular methods having certain steps. However, the method and system operate effectively for other methods having different and/or additional steps and steps in different orders that are not inconsistent with the exemplary embodiments. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features described herein.

A method and system for providing a magnetic junction are described. The method and system include providing a free layer, a symmetry filter, and a pinned layer. The free layer has a first magnetic moment switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction. The symmetry filter transmits charge carriers having a first symmetry with higher probability than the charge carriers having other symmetries. The pinned layer has a second magnetic moment pinned in a particular direction. The symmetry filter resides between the free layer and the pinned layer. At least one of the free layer and the pinned layer has the charge carriers of the first symmetry in one spin channel at the Fermi level, lacks the charge carriers of the first symmetry at the Fermi level in the other spin channel, lies in a plane, and has a nonzero magnetic moment component substantially perpendicular to the plane. The free layer and/or the pinned layer and the symmetry filter has at least one lattice mismatch of less than seven percent. In some aspects, the at least one lattice mismatch may be less than three percent or four percent. In some aspects, the symmetry filter includes at least one of Ge, GaAs and ZnSe.

The exemplary embodiments are described in the context of particular magnetic junctions and magnetic memories having certain components. One of ordinary skill in the art will readily recognize that the present invention is consistent with the use of magnetic junctions and magnetic memories having other and/or additional components and/or other features not inconsistent with the present invention. The method and system are also described in the context of current understanding of the spin transfer phenomenon. Consequently, one of ordinary skill in the art will readily recognize that theoretical explanations of the behavior of the method and system are made based upon this current understanding of spin transfer. One of ordinary skill in the art will also readily recognize that the method and system are described in the context of a structure having a particular relationship to the substrate. However, one of ordinary skill in the art will readily recognize that the method and system are consistent with other structures. In addition, the method and system are described in the context of certain layers being synthetic and/or simple. However, one of ordinary skill in the art will readily recognize that the layers could have another structure. Furthermore, the method and system are described in the context of magnetic junctions having particular layers. However, one of ordinary skill in the art will readily recognize that magnetic junctions having additional and/or different layers not inconsistent with the method and system could also be used. Moreover, certain components are described as being magnetic, ferromagnetic, and ferrimagnetic. As used herein, the term magnetic could include ferromagnetic, ferrimagnetic or like structures. Thus, as used herein, the term “magnetic” or “ferromagnetic” includes, but is not limited to ferromagnets and ferrimagnets. The method and system are also described in the context of single elements. However, one of ordinary skill in the art will readily recognize that the method and system are consistent with the use of magnetic memories having multiple elements. Further, as used herein, “in-plane” is substantially within or parallel to the plane of one or more of the layers of a magnetic junction. Conversely, “perpendicular” corresponds to a direction that is substantially perpendicular to one or more of the layers of the magnetic junction.

FIG. 2 depicts an exemplary embodiment of a magnetic junction **100**. For example, the magnetic junction **100** may be used in magnetic memory in which current is to be driven through the magnetic junction **100** in a CPP direction. For clarity, FIG. 2 is not drawn to scale and some portions of the magnetic junction **100** might be omitted. The magnetic junction **100** includes a pinned layer **110**, a spin filter **120**, and a free layer **130**. The magnetic junction **100** may also include other layer(s) (not shown).

The free layer **130** is a magnetic layer having a changeable magnetic moment **131**. The magnetic moment **131** is shown as having arrows at both ends to indicate that the magnetic moment **131** may change direction. The magnetic moment **131** is switchable between stable magnetic states when a write current is passed through the magnetic junction **100**. Thus, in the exemplary embodiment depicted in FIG. 2, spin transfer torque may be used to switch the magnetic moment **131** of the free layer **130**. For example current driven in the z direction can switch the magnetic moment **131** to be parallel or antiparallel to the magnetic moment **111** of the pinned layer **110**. In some embodiments, the free layer **130** has a thickness of at least one nanometer and not more than ten nanometers. However, other thicknesses are possible. Although depicted as a simple layer with a single magnetic moment **131**, the free layer **130** may also include multiple ferromagnetic and/or nonmagnetic layers. For example, the free layer **130** may be a synthetic antiferromagnet (SAF) including magnetic layers antiferromagnetically or ferromagnetically coupled through one or more thin layers, such as Ru. The free layer **130** may also be another multilayer in which one or more sublayers are magnetic. Other structures for the free layer **130** may also be used.

In the embodiment shown, the free layer **130** has an easy axis along the magnetic moment **131**. The magnetic moment **131** is stable along the easy axis. In the embodiment shown, the magnetic moment has a component in-plane. Stated differently, the magnetic moment **131** has a component that is substantially within the plane of the free layer **130**. In the embodiment shown, therefore, the magnetic moment **131** has a component parallel to the x-y plane. In addition, the free layer magnetic moment **131** has a component that is substantially perpendicular to plane. Stated differently the free layer magnetic moment **131** has a component parallel to the z-axis of FIG. **2**. In some embodiments, the magnetic moment **131** may be perpendicular to plane. In such embodiments, the in-plane component of the magnetic moment **131** is zero. In such embodiments, the free layer **130** may include materials such as AlMn. In some such embodiments, the free layer **130** may consist of AlMn in an $L1_0$ phase, with a (100) axis perpendicular to the plane. In other embodiments, the free layer **130** may include MnGa and/or MnIn.

The symmetry filter **120** is a layer that transmits charge carriers having a first symmetry with higher probability than the charge carriers having another symmetry. Transmission may be via tunneling. In some embodiments, the symmetry filter **120** transmits only charge carriers that have the first symmetry with a higher probability. All other symmetries would have a lower probability of transmission. For example, the symmetry filter **120** may be crystalline MgO having a (100) texture. Such a layer transmits current carriers with wave functions having a Δ_1 symmetry in the (100) direction with higher probability than current carriers with wave functions having other symmetries. Thus, the symmetry filter **120** may be considered to function in a similar manner to a filter that passes current carriers that have the first symmetry, but does not pass the current carriers having other symmetries. In other embodiments, other materials may be used. For example, $SrSnO_3$ may be used. Although insulators used as tunneling barriers are described for the symmetry filter **120**, in other embodiments other materials having other electrical properties may be used.

The pinned layer **110** has a magnetic moment **111** pinned in a particular direction. For example, the magnetic moment **111** may be pinned by an AFM layer (not shown), a hard magnetic (not shown) or via some other mechanism. The pinned layer **110** shown is a simple layer, consisting of a single magnetic layer. Although depicted as a simple layer with a single magnetic moment **111**, the pinned layer **110** may include multiple layers. For example, the pinned layer **110** may be a SAF including magnetic layers antiferromagnetically or ferromagnetically coupled through one or more thin layers, such as Ru. The pinned layer **110** may also be another multilayer in which one or more sublayers are magnetic. Other structures for the pinned layer **110** may also be used.

In the embodiment shown, the magnetic moment **111** is pinned such that it has a component in-plane. Stated differently, the magnetic moment **111** has a component that is substantially within the plane of the pinned layer **110**. In the embodiment shown, therefore, the magnetic moment **111** has a component parallel to the x-y plane. In addition, the magnetic moment **111** has a component that is substantially perpendicular to plane. Stated differently the magnetic moment **111** has a component parallel to the z-axis of FIG. **2**. In some embodiments, the magnetic moment **111** may be perpendicular to the plane. In such embodiments, the magnetic moment **111** has a zero in-plane component. In such embodiments, the pinned layer **110** may include materials such as AlMn. In some such embodiments, the pinned layer **110** may consist of AlMn in an $L1_0$ phase, with a (100) orientation. In other embodiments, the pinned layer **110** may include MnGa.

The free layer **130** and/or the pinned layer **110** are configured such that at least one of the layers **110** and **130** has the charge carriers of the symmetry transmitted by the symmetry filter **120** at a Fermi level in one spin channel. In addition, at least one of the free layer **130** and the pinned layer **110** lacks the charge carriers of the symmetry at the Fermi level in another spin channel. Such a free layer and/or pinned layer **110** also has a component of its magnetization **131**/**111** perpendicular to plane. For example, the free layer **130** and/or the pinned layer **110** may have charge carriers with the symmetry at the Fermi level in a majority spin channel but not have the charge carriers with the symmetry at the Fermi level in a minority spin channel. In a ferromagnetic material, the majority spin channel has electrons with their spins aligned with the net magnetization direction. The minority spin channel electrons have their spins antiparallel to the majority spin channel electrons. For a symmetry filter **120** that transmits current carriers having a Δ_1 symmetry, such as MgO having a (100) texture, the layers **110** and/or **130** may have current carriers of Δ_1 symmetry at the Fermi level in the majority spin channel. However, the minority spin channel either does not have current carriers of Δ_1 symmetry or has current carriers of Δ_1 symmetry spaced from the Fermi level. In some embodiments, the layer **110** and/or **130** having these properties also has a magnetization perpendicular to plane.

For example, it has been discovered that a free layer **130** and/or pinned layer **110** including AlMn of a $L1_0$ phase and (100) orientation has a perpendicular magnetic moment and has desired symmetries at the Fermi level. More specifically, if the pinned layer **110** includes AlMn in the $L1_0$ phase with its (100) axis perpendicular to plane, the pinned layer **110** would have a magnetic moment **111** perpendicular to plane. In addition, the pinned layer **110** would have charge carriers having a Δ_1 symmetry at the Fermi level in the majority spin channel. Charge carriers having the Δ_1 symmetry for the majority spin channel are thus more likely to carry current through the pinned layer **110**. The pinned layer **110** having such a composition and structure also has no charge carriers in the minority spin channel with a Δ_1 symmetry in the (001) direction. The band structure **160** of an exemplary embodiment of such a layer is depicted in FIG. **3**. Note, however, that the energy bands shown are for exemplary purposes only, and not intended to accurately reflect the band structure of such a material. As can be seen in the band structure, the majority spin channel has Δ_1 symmetry charge carriers at the Fermi level. As such, Δ_1 symmetry charge carriers are likely to carry current through the pinned layer **110**. A free layer **130** having the same crystal structure and composition may have similar properties. Similarly, a free layer **130** and/or pinned layer **110** may include MnGa and have analogous properties to those described above.

Such a pinned layer **110** and/or free layer **130** may be used in conjunction with a spin filter **120** that has a high probability for transmitting charge carriers having a Δ_1 symmetry, but a lower probability for transmission of charge carrier having wave functions of other symmetries. Thus, although all wave functions for charge carriers are expected to decay in an insulating spin filter, the Δ_1 wave functions decay more slowly. From the point of view of transmission and reflection, the charge carriers with Δ_1 symmetry are transmitted with higher probability than the electrons with wave functions of other symmetries. The charge carriers that are not transmitted may be reflected. For example, MgO having a (100) orientation tends to transmit electrons with wave functions having a particular, Δ_1, symmetry with a higher probability than electrons with wave functions having other symmetries. FIG. **4** illustrates the relatively slow decay of the Δ_1 wave function in the MgO compared to the states of other symmetries. Because the majority spin channel has Δ_1 symmetry at the Fermi level, majority charge carriers from the Fermi level in the pinned layer **110** and the free layer **130** are much more likely to be transmitted through the spin filter **120**. As a result, a high degree of spin polarization may be achieved. Thus, efficiency of the spin torque induced transitions may be improved, and the critical current reduced. In this manner, the magnetic junction **100** functions in a similar manner to the conventional magnetic junction **100**, which uses CoFe having Δ_1 electrons in at the Fermi level in the majority spin channel and no Δ_1 electrons at the Fermi level in the minority spin channel.

Further, for a material such as AlMn, the magnetic moment **111**/**131** may be perpendicular to plane. For AlMn, therefore, the quantity $\langle H\rangle_{eff}/H_k$ is at or close to one. This feature may further reduce the critical current. As a result, performance of the magnetic junction **100** may be improved. Thus, the magnetic junction **100** may be used in a magnetic memory, such as STT-RAM, having improved performance. Other uses of the magnetic junction **100** are also possible.

In addition, the symmetry filter **120** may have additional properties with respect to the pinned layer **110** and/or the free layer **130**. In some embodiments, the lattice mismatch between one or both of the layers **110** and **130** adjoining the symmetry filter **120** may be desired to be low. For example, the lattice mismatch between the layer **120** and the layer(s) **110** and/or **130** may be less than seven percent. In some embodiments, the lattice mismatch between the layer **120** and the layer(s) **110** and/or **130** may be less than three percent or four percent. The lattice mismatch is the difference between the lattice sites for adjoining layers. The lattice mismatch thus depends upon both the lattice parameters of the layers and the texture of the layers. The smaller lattice mismatch may give rise to an increased probability that the magnetic layer(s) **110** and/or **130** have the desired magnetic anisotropy. In some embodiments, MgO (001) may have a lattice mismatch of at least seven percent with $L1_0$ AlMn. In some embodiments, this larger lattice mismatch may result in the pinned layer **110** and/or the free layer **130** having a different magnetic anisotropy. This mismatch induced magnetic anisotropy may result in an in-plane magnetic moment for the free layer **130** and/or the pinned layer **110**. In some embodiments, this is undesirable. Further, in some cases the lattice mismatch may adversely affect the band structure. This can result in reduced polarization of current carriers, which is undesirable. Consequently, a reduced lattice mismatch may be desired to achieve a desired magnetic anisotropy and/or spin polarization. For example, the free layer **130** and/or the pinned layer **110** may have a higher perpendicular magnetic anisotropy and a perpendicular-to-plane magnetic moment. Similarly, the free layer **130** and/or pinned layer **110** may have more electrons in a majority spin channel and fewer (or no) electrons in the other spin channel.

The reduced lattice mismatch may be achieved in a number of ways. In some embodiments, the lattice of the symmetry filter layer **120** is contracted or expanded to be closer to that of the pinned layer **110** and/or free layer **130**. For example, the lattice parameter of MgO used in the symmetry filter **120** may be larger than the lattice parameter of the material (e.g. AlMn $L1_0$) used in the pinned layer **110** and/or free layer **130**. Thus, the lattice of the symmetry filter layer **120** is desired to be contracted. In some embodiments, this is achieved by using Ge, GaAs, ZnSe, or other symmetry filters having a lattice parameter that is lower than the lattice parameter of MgO in the symmetry filter **120**. The lattice parameter of the symmetry filter **120** is thus closer to the lattice parameter of AlMn $L1_0$ and/or other material(s) used for the pinned layer **110**/free layer **130**. The resulting lattice mismatch between the symmetry filter layer **120** and the pinned layer **110** and/or free layer **130** may be less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **120** and the layer(s) **110** and/or **130** may be less than three percent or four percent. Thus, the lattice of the material used for the symmetry layer **120** may be contracted to be closer to that of the pinned layer **110** and/or free layer **130**. In other embodiments, the lattice of the pinned layer **110** and/or free layer **130** may be expanded. In some embodiments, this might be achieved through doping or other mechanisms that can increase the lattice parameter of AlMn or other material used in the layer(s) **110** and/or **130**. In other embodiments, other material(s) may be used for the layer(s) **110** and/or **130**. For example, MnGa and/or MnIn may be used. However, the mechanisms used to more closely match the lattices are desired not to unduly interfere with the magnetic properties of the layers **110** and **130**.

FIG. **5** depicts another exemplary embodiment of a magnetic junction **100'** that may be used in a magnetic memory. For clarity, FIG. **5** is not to scale. The magnetic junction **100'** includes components analogous to the magnetic junction **100** depicted in FIG. **2**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100'** includes a pinned layer **110'**, a symmetry filter **120'**, and a free layer **130'** analogous to the pinned layer **110**, the symmetry filter **120**, and the free layer **130**, respectively. Also shown are seed layer(s) **102**, pinning layer **104**, and capping layer **106**. In other embodiments, the seed layer(s) **102**, pinning layer **104**, and/or capping layer **106** may be omitted. In addition, contacts (not shown) may also be provided to drive current in the desired direction. The seed layer(s) **102** may be used to provide a template for the desired crystal structure of the pinning layer **104**. The pinning layer **104** may include an AFM layer, a hard magnet or other material used to pin the magnetization of the pinned layer **110'**.

In the embodiment shown, the magnetic moment **111'** of the pinned layer **110'** and the magnetic moment **131'** of the free layer **130'** are perpendicular to plane. In addition, both the free layer **130'** and the pinned layer **110'** are configured such that each of the layers **110'** and **130'** has its charge carriers of the symmetry transmitted by the symmetry filter **120** with a higher probability at a Fermi level in a first spin channel, such as the majority spin channel. In some embodiments, at least one of the free layer **130'** and the pinned layer **110'** lacks the charge carriers of the symmetry at the Fermi level in the other spin channel (e.g. the minority spin channel). For example, both the pinned layer **110'** and the free layer **130'** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. Such a material has Δ_1 electrons at the Fermi level in the majority spin channel, but no Δ_1 electrons in the (100) direction in the minority spin channel. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **120'**. In some embodiments, the lattice mismatch between the symmetry filter **120'** and the layer(s) **110'** and/or **130'** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **120'** and the layer(s) **110'** and/or **130'** may be less than three percent or four percent. For example, the symmetry filter **120'** may include Ge, GaAs and or ZnSe. The pinned layer **110'** and/or the free layer **130'** may include MnGa and/or MnIn.

The magnetic junction **100'** shares the benefits of the magnetic junction **100**. Because the magnetic moments **111'** and **131'** are perpendicular to plane, the quantity $<H>_{eff}/H_k$ is one. In addition, the spin polarization efficiency may be improved. Consequently, performance of the magnetic junction may be enhanced.

FIG. **6** depicts another exemplary embodiment of a magnetic junction **100"** suitable for use in a magnetic memory. For clarity, FIG. **6** is not to scale. The magnetic junction **100"** includes components analogous to the magnetic junctions **100/100'**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100"** includes a pinned layer **110"**, a symmetry filter **120"**, and a free layer **130"** analogous to the pinned layer **110/110'**, the symmetry filter **120/120'**, and the free layer **130/130'**, respectively. Also shown are seed layer(s) **102'**, pinning layer **104'**, and capping layer **106'**. In other embodiments, the seed layer(s) **102'**, pinning layer **104'**, and/or capping layer **106'** may be omitted. The seed layer(s) **102'** may be used to provide a template for the desired crystal structure of the pinning layer **104'**. The pinning layer **104'** may include an AFM layer, a hard magnet or other material used to pin the magnetization of the pinned layer **110"**. In addition, contacts (not shown) may also be provided to drive current in the desired direction.

In the embodiment shown, the magnetic moment **131"** of the free layer **130"** is perpendicular to plane. In addition, the free layer **130"** is configured such that the layer and **130'** has its charge carriers of the symmetry transmitted by the symmetry filter **120"** with a higher probability at a Fermi level in a spin channel, such as a majority spin channel. In some embodiments, the free layer **130"** lacks the charge carriers of the symmetry at the Fermi level in the other spin channel, such as the minority spin channel. For example, the free layer **130"** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **120"**. The pinned layer **110"** may include other magnetic materials. For example, the pinned layer **110"** include bcc (001) Fe, bcc (001) Co, and/or bcc (001) FeCo. In some embodiments, the pinned layer **110"** may still have its magnetization (not shown in FIG. **6**) perpendicular to the plane. However, other orientations are possible. In some embodiments, the lattice mismatch between the symmetry filter **120"** and the layer(s) **110"** and/or **130"** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **120"** and the layer(s) **110"** and/or **130"** may be less than three percent or four percent. For example, the symmetry filter **120"** may include Ge, GaAs and or ZnSe. The pinned layer **110"** and/or the free layer **130"** may include MnGa and/or MnIn.

The magnetic junction **100"** shares the benefits of the magnetic junctions **100/100'**. Because the magnetic moment **131'** is perpendicular to plane, the quantity $<H>_{eff}/H_k$ is one. In addition, the spin polarization efficiency may be improved. Consequently, performance of the magnetic junction **100"** may be enhanced.

FIG. **7** depicts another exemplary embodiment of a magnetic junction **100'"** suitable for use in a magnetic memory. For clarity, FIG. **7** is not to scale. The magnetic junction **100'"** includes components analogous to the magnetic junctions **100/100'/100"**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **100'"** includes a pinned layer **110'"**, a symmetry filter **120'"**, and a free layer **130'"** analogous to the pinned layer **110/110'/110"**, the symmetry filter **120/120'/120"**, and the free layer **130/130'/130"**, respectively. Also shown are seed layer(s) **102"**, pinning layer **104"**, and capping layer **106"**. In other embodiments, the seed layer(s) **102"**, pinning layer **104"**, and/or capping layer **106"** may be omitted. The seed layer(s) **102"** may be used to provide a template for the desired crystal structure of the pinning layer **104"**. The pinning layer **104'"** may include an AFM layer, a hard magnet or other material used to pin the magnetization of the pinned layer **110'"**. In addition, contacts (not shown) may also be provided to drive current in the desired direction.

In the embodiment shown, the magnetic moment **111'"** of the pinned layer **110'"** is perpendicular to plane. In addition, the pinned layer **110'"** is configured such that the pinned layer **110'"** has its charge carriers of the symmetry transmitted by the symmetry filter **120'"** at a Fermi level in a majority spin channel. In some embodiments, the pinned layer **110'"** lacks the charge carriers of the symmetry at the Fermi level in a minority spin channel. For example, the pinned layer **110'"** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **120'"**. The free layer **130'"** may include other magnetic materials. For example, the free layer **130'"** include bcc (001) Fe, bcc (001) Co, and/or bcc (001) FeCo. In the embodiment shown, the free layer **130'"** has its magnetization **131'"0** perpendicular to plane. However, other orientations are possible. In some embodiments, the lattice mismatch between the symmetry filter **120'"** and the layer(s) **110'"** and/or **130'"** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **120'"** and the layer(s) **110'"** and/or **130"** may be less than three percent or four percent. For example, the symmetry filter **120'"** may include Ge, GaAs and or ZnSe. The pinned layer **110'"** and/or the free layer **130'"** may include MnGa and/or MnIn.

The magnetic junction **100'"** shares the benefits of the magnetic junctions **100/100'/100"**. Because the magnetic moment **111'"** is perpendicular to plane, the quantity $<H>_{eff}/H_k$ is one. In addition, the spin polarization efficiency may be improved. Consequently, performance of the magnetic junction **100'"** may be enhanced.

FIG. **8** depicts another exemplary embodiment of a magnetic junction **200** suitable for use in a magnetic memory. For clarity, FIG. **8** is not to scale. The magnetic junction **200** includes components analogous to the magnetic junctions **100/100'** depicted in FIGS. **2** and **5**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **200** includes a pinned layer **210**, a symmetry filter **220**, and a free layer **230** analogous to the pinned layer **110/110'**, a symmetry filter **120/120'**, and the free layer **130/130'**, respectively. Also shown are seed layer(s) **202**, pinning layer **204**, and capping layer **206** analogous to seed layer **102**, pinning layer **104**, and capping layer **106**, respectively. In other embodiments, the seed layer(s) **202**, pinning layer **204**, and/or capping layer **206** may be omitted. In addition, contacts (not shown) may also be provided to drive current in the desired direction.

In the embodiment shown, the pinned layer **210** and the free layer **230** are SAFs. Thus, the pinned layer **210** includes ferromagnetic layers **212** and **216** separated by nonmagnetic spacer layer **214**. Similarly, the free layer **230** includes ferromagnetic layers **232** and **236** separated by nonmagnetic spacer layer **234**. Spacer layers **214** and **234** are typically Ru.

In the embodiment shown, the magnetic moments **211** and **215** of the pinned layer **210** and the magnetic moments **231** and **235** of the free layer **230** are perpendicular to plane. In addition, both the free layer **130'** and the pinned layer **110'** are configured such that each of the layers **210** and **230** has its charge carriers of the symmetry transmitted by the symmetry filter **220** at a Fermi level in a spin channel, such as majority spin channel. In some embodiments, at least one of the free layer **230** and the pinned layer **210** lacks the charge carriers of the symmetry at the Fermi level in the other spin channel, such as a minority spin channel. For example, both the ferromagnetic layers **212** and **216** of the pinned layer **210** and the ferromagnetic layers **232** and **236** free layer **230** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. However, for such embodiments, the spacer layers **214** and **234** are capable of allowing for antiferromagnetic coupling between the ferromagnetic layers **212** and **216** and between the layers **232** and **236**. In addition, the spacer layers **214** and **234** would provide the appropriate growth template for the desired crystal structure and texture of the layers **216** and **236**. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **220**. In some embodiments, the lattice mismatch between the symmetry filter **220** and the layer(s) **216** and/or **232** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **220** and the layer(s) **216** and/or **232** may be less than three percent or four percent. For example, the symmetry filter **220** may include Ge, GaAs and or ZnSe. The layer **232** and/or the layer **216** may include MnGa and/or MnIn.

FIG. **9** depicts another exemplary embodiment of a magnetic junction **200'** suitable for use in a magnetic memory. For clarity, FIG. **9** is not to scale. The magnetic junction **200'** includes components analogous to the magnetic junctions **100/100'/200**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **200'** includes a pinned layer **210'**, a symmetry filter **220'**, and a free layer **230'** analogous to layers **210/110/110'**, **220/120/120'**, and **230/130/130'**, respectively. Also shown are seed layer(s) **202'**, pinning layer **204'**, and capping layer **206'**. In other embodiments, the seed layer(s) **202'**, pinning layer **204'**, and/or capping layer **206'** may be omitted. The seed layer(s) **202'** may be used to provide a template for the desired crystal structure of the pinning layer **204'**. The pinning layer **204'** may include an AFM layer, a hard magnet or other material used to pin the magnetization of the pinned layer **210"**. In addition, contacts (not shown) may also be provided to drive current in the desired direction.

In the embodiment shown, the free layer **230'** is a SAF including layers **232'**, **234'**, and **236'** analogous to layers **232**, **234**, and **236**. In the embodiment shown, the magnetic moments **231** and **235** of the free layer **230'** are perpendicular to plane. In other embodiments, the magnetic moment of the pinned layer **210'** is perpendicular to plane. In addition, the free layer **230'** is configured such that the layer **230'** has its charge carriers of the symmetry transmitted by the symmetry filter **220'** at a Fermi level in a majority spin channel. In some embodiments, the free layer **230'** lacks the charge carriers of the symmetry at the Fermi level in a minority spin channel. For example, the free layer **230'** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **220'**.

In the embodiment shown, the magnetic moments **231'** and **235'** of the free layer **230'** are perpendicular to plane. In addition, the free layer **230'** is configured such that the layer **230'** has its charge carriers of the symmetry transmitted by the symmetry filter **220'** with a higher probability at a Fermi level in one spin channel. For example, the majority spin channel may include charge carriers of the symmetry at the Fermi level. In some embodiments, the free layer **230'** lacks the charge carriers of the symmetry transmitted with a higher probability at the Fermi level in the other spin channel, such as the minority spin channel. For example, the free layer **130'** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **220'**. The pinned layer **210'** may include other magnetic materials. For example, the pinned layer **210'** include bcc (001) Fe, bcc (001) Co, and/or bcc (001) FeCo. Although the pinned layer magnetic moment **211'**is shown as perpendicular to plane, other orientations are possible. In some embodiments, the lattice mismatch between the symmetry filter **220'** and the layer(s) **210'** and/or **232'** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **220'** and the layer(s) **210'** and/or **232'** may be less than three percent or four percent. For example, the symmetry filter **220'** may include Ge, GaAs and or ZnSe. The layer **232'** and/or the layer **210'** may include MnGa and/or MnIn.

FIG. **10** depicts another exemplary embodiment of a magnetic junction **200"** suitable for use in a magnetic memory. For clarity, FIG. **10** is not to scale. The magnetic junction **200"** includes components analogous to the magnetic junctions **100/100"/200/200'**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **200"** includes a pinned layer **210"**, a symmetry filter **220"**, and a free layer **230"** analogous to layers **210/210'/110/110'**, **220/220'/120/120'**, and **230/230'/130/130'**, respectively. Also shown are seed layer(s) **202"**, pinning layer **204"**, and capping layer **206"**. In other embodiments, the seed layer(s) **202"**, pinning layer **204"**, and/or capping layer **206"** may be omitted. The seed layer(s) **202"** may be used to provide a template for the desired crystal structure of the pinning layer **204"**. The pinning layer **204"** may include an AFM layer, a hard magnet or other material used to pin the magnetization of the pinned layer **210"**. In addition, contacts (not shown) may also be provided to drive current in the desired direction.

In the embodiment shown, the pinned layer **210"** is a SAF including layers **212'**, **214'**, and **216'** analogous to layers **212**, **214**, and **216**. In the embodiment shown, the magnetic moments **211'** and **215'** of the pinned layer **210"** are perpendicular to plane. In other embodiments, the magnetic moment of the free layer **230"** is perpendicular to plane. In addition, the pinned layer **210"** is configured such that the layer **210"** has its charge carriers of the symmetry transmitted by the symmetry filter **220"** with a higher probability at a Fermi level in a spin channel (e.g. the majority spin channel). In some embodiments, the pinned layer **210"** lacks the charge carriers of the symmetry at the Fermi level in the other spin channel (e.g. a minority spin channel). For example, the pinned layer **210"** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **220"**.

In the embodiment shown, the magnetic moments **211** and **215** of the pinned layer **210"** are perpendicular to plane. In addition, the pinned layer **210"** is configured such that the layer **210"** has its charge carriers of the symmetry transmitted by the symmetry filter **220"** with a higher probability at a Fermi level in one spin channel such as a majority spin channel. In some embodiments, the pinned layer **210"** lacks the charge carriers of the symmetry at the Fermi level in the other spin channel, such as a minority spin channel. For example, the pinned layer **210"** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. In addition MgO having a (100) texture or $SrSnO_3$ may be used as the spin filter **220"**. The free layer **230"** may include other magnetic materials. For example, the free layer **230"** include bcc (001) Fe, bcc (001) Co, and/or bcc (001) FeCo. Although the free layer magnetic moment **231"** is shown as perpendicular to plane, other orientations are possible. In some embodiments, the lattice mismatch between the symmetry filter **220"** and the layer(s) **216'** and/or **230"** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **220"** and the layer(s) **216'** and/or **230"** may be less than three percent or four percent. For example, the symmetry filter **220"** may include Ge, GaAs and or ZnSe. The layer **230"** and/or the layer **216'** may include MnGa and/or MnIn.

The magnetic junctions **200**, **200'**, and **200"** share the benefits of the magnetic junctions **100/100'/100"**. Because the magnetic moments of the layers **210/210'/210"** and **230/230'/230"** may be perpendicular to plane, the quantity $\langle H\rangle_{eff}/H_k$ is one. In addition, the spin polarization efficiency may be improved. Consequently, performance of the magnetic junctions **200**, **200'**, and **200"** may be enhanced.

FIG. **11** depicts another exemplary embodiment of a magnetic junction **300** suitable for use in a magnetic memory. For clarity, FIG. **11** is not to scale. The magnetic junction **300** includes components analogous to the magnetic junctions **100/100'/100"/100"/200/200'/200"** depicted in FIGS. **2** and **5-10**. Consequently, analogous components are labeled similarly. Thus, the magnetic junction **300** includes a pinned layer **310**, a symmetry filter **320**, and a free layer **330** analogous to the pinned layer **110/110'/210**, a symmetry filter **120/120'/220**, and the free layer **130/130'/230**, respectively. Also shown are seed layer(s) **302**, pinning layer **304**, and capping layer **306** analogous to seed layer **102/102'/102"/202/202'/202"**, pinning layer **104/104'/104"/204/204'/204"/204'"**, and capping layer **106/106'/106"/206/206'/206"**, respectively. In other embodiments, the seed layer(s) **302**, pinning layer **304**, and/or capping layer **306** may be omitted. The magnetic junction **300** also includes an additional spacer layer **340**, an additional pinned layer **350**, and an additional pinning layer **360**. Thus, the magnetic junction **300** may be considered to include a magnetic element analogous to the magnetic elements **100/100'/100"/100'"/200/200'/200"** plus additional layers **340**, **350**, and **360**.

In the embodiment shown, the additional spacer layer **340** may be a tunneling barrier layer. In other embodiments, the additional spacer layer **340** may be conductive. Further, in some embodiments the additional spacer layer **340** may be a symmetry filter, such as MgO described above. The additional pinned layer **350** may be analogous to the layers **110/110'/110"/110'"/210/210'/210"**. Thus, the pinned layer **350** may have its charge carriers of the symmetry transmitted by the symmetry filter **320** with a higher probability at a Fermi level in a spin channel, such as the majority spin channel. In some embodiments, the additional pinned layer **350** lacks the charge carriers of the symmetry at the Fermi level in another spin channel, such as the minority spin channel. For example, both the pinned layer **350** may include AlMn having an $L1_0$ crystal structure and a (100) axis perpendicular to plane. The magnetic moment **351** of the additional pinned layer may thus be perpendicular to plane. Note that although the magnetic moments **311** and **351** are shown anti-parallel, other configurations may be used. In addition MgO having a (100) texture or $SrSnO_3$ may be used so that the spacer layer **340** acts as a spin filter. Further, although shown as simple layers, one or more of the layers **310**, **330**, and **350** may be a SAF. In some embodiments, the lattice mismatch between the symmetry filter **320** and the layer(s) **330** and/or **310** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **320** and the layer(s) **310** and/or **330** may be less than three percent or four percent. For example, the symmetry filter **320** may include Ge, GaAs and or ZnSe. The layer **330** and/or the layer **310** may include MnGa and/or MnIn. Similarly, if the layer **340** is a symmetry filter, then the lattice mismatch between the symmetry filter **340** and the layer(s) **330** and/or **360** is less than seven percent. In some embodiments, the lattice mismatch between the symmetry filter layer **340** and the layer(s) **330** and/or **360** may be less than three percent or four percent. For example, the symmetry filter **340** may include Ge, GaAs and or ZnSe. The layer **330** and/or the layer **360** may include MnGa and/or MnIn.

The dual magnetic junctions **300** shares the benefits of the magnetic junctions **100/100'/100"/200/200'/200"**. Because the magnetic moments of the layers **210/210'/210"/310**, **230/230'/230"/330**, and optionally **350** may be perpendicular to plane, the quantity $\langle H\rangle_{eff}/H_k$ is one. In addition, the spin polarization efficiency may be improved. Consequently, performance of the magnetic junction **300** may be improved.

FIG. **12** depicts an exemplary embodiment of a magnetic memory **400** utilizing a dual magnetic junction. In the embodiment shown, the magnetic memory is a STT-RAM **400**. The magnetic memory **400** includes reading/writing column selector/drivers **402** and **406** as well as word line selector/driver **404**. The magnetic memory **400** also includes memory cells **410** including a magnetic junction **412** and a selection/isolation device **414**. The magnetic junction **412** may be any magnetic junction **100/100'/100"/100'"/200/200'/200"/300**. The reading/writing column selector/drivers **402** and **406** may be used to selectively drive current through the bit lines **403** and thus the cells **410**. The word line selector/driver **404** selectively enables row(s) of the magnetic memory **400** by enabling the selection/isolation device **414** coupled with the selected word line **405**.

Because the magnetic memory **400** may use the magnetic junctions **100/100'/100"/100'"/200/200'/200"/300**, the magnetic memory **400** share the benefits of the magnetic junctions **100/100'/100"/100'"/200/200'/200"**. Consequently, performance of the magnetic memory **400** may be improved.

FIG. **13** depicts an exemplary embodiment of a method **500** for fabricating dual magnetic tunneling junction suitable for use in a magnetic memory. The method **500** is described in the context of the magnetic junctions **100/100'**. However, the method **500** may also be used to fabricate other magnetic junctions. In addition, for simplicity, some steps may be omitted. In addition, the method **500** may combine and/or use additional and/or other steps. The method **500** is also described in the context of fabricating a single magnetic junction. However, the method **500** generally forms multiple magnetic junctions in parallel, for example for the memory **300**.

A magnetic junction stack is provided, via step **502**. The magnetic junction stack includes a pinned layer film, a spin filter film, and a free layer film. The stack may also include a spacer layer film and an additional pinned layer film if the magnetic junction **300** is to be fabricated. In some embodiments, the magnetic junction stack may also be annealed in step **502**.

The magnetic junction **100/100'/100"/100'"/200/200'/200"/300** is defined from the magnetic junction stack, via step **504**. Step **504** includes providing a mask that covers a portion of the magnetic junction stack, then removing the exposed portions of the magnetic junction stack. The magnetic junction **100/100'/100"/100'"/200/200'/200"/300** includes a pinned layer **110/110'/110"/110'"/210/210'/210"/310** defined from the first pinned layer film, a symmetry filter **120/120'/**

120"/220/220'/220"/320 defined from the spin filter film, and a free layer 130/130'/130"/130'"/230/230'/7230"330 defined from the free layer film. In some embodiments, the magnetic junction 300 also includes a spacer layer 340 and an additional pinned layer 350.

The magnetization directions of the pinned layers 110/110'/110"/110'"/210/210'/210"/310 are set, via step 506. For example, step 506 may be performed by applying a magnetic field in the desired direction while the magnetic junction 100/100'/100"/100'"/200/200'/200"/300 are heated, then cooling the magnetic junction 100/100'/100"/100'"/200/200'/200"/300 in the presence of the field.

Thus, the magnetic junction 100/100'/100"/100'"/200/200'/200"/300 may be fabricated. A magnetic junction and/or the magnetic memory 400 fabricated through the method 500 shares the benefits of the magnetic junctions 100/100'/100"/100'"/200/200'/200" and/or the magnetic memory 300. Consequently, performance of the magnetic junctions 100/100'/100"/200/200'/200" and/or the magnetic memory 300 may be improved.

A method and system for providing a magnetic junction and memory fabricated using the magnetic memory junction has been described. The method and system have been described in accordance with the exemplary embodiments shown, and one of ordinary skill in the art will readily recognize that there could be variations to the embodiments, and any variations would be within the spirit and scope of the method and system. Accordingly, many modifications may be made by one of ordinary skill in the art without departing from the spirit and scope of the appended claims.

I claim:

1. A magnetic junction comprising:

a free layer having a first magnetic moment switchable between a plurality of stable magnetic states when a write current is passed through the magnetic junction;

a symmetry filter that transmits charge carriers having a first symmetry with a higher probability than the charge carriers having a second symmetry;

a pinned layer having a second magnetic moment pinned in a particular direction, the symmetry filter residing between the free layer and the pinned layer;

wherein at least one of the free layer and the pinned layer has the charge carriers of the first symmetry at a Fermi level in a spin channel, lacks the charge carriers of the first symmetry at the Fermi level in another spin channel, lies substantially in a plane and has a nonzero magnetic moment component substantially perpendicular to the plane, the symmetry filter and at least one of the free layer and the pinned layer having a lattice mismatch of less than seven percent.

2. The magnetic junction of claim **1** wherein the lattice mismatch is less than four percent.

3. The magnetic junction of claim **1** wherein the at least one of the free layer and the pinned layer include AlMn.

4. The magnetic junction of claim **1** wherein the symmetry filter includes at least one of Ge, GaAs and ZnSe.

5. The magnetic junction of claim **1** wherein the first magnetic moment is substantially perpendicular to the plane.

6. The magnetic junction of claim **1** wherein the second magnetic moment is substantially perpendicular to the plane.

7. The magnetic junction of claim **1** wherein the at least one of the free layer and the pinned layer includes at least one of MnGa and MnIn.

8. The magnetic junction of claim **1** wherein the symmetry filter is a tunneling barrier layer.

9. The magnetic junction of claim **1** wherein at least one of the free layer and the pinned layer is a synthetic antiferromagnet.

10. The magnetic junction of claim **1** further comprising:

a spacer layer; and

an additional pinned layer, the spacer residing between the free layer and the additional pinned layer, the additional pinned layer having a third magnetic moment.

11. The magnetic junction of claim **10** wherein the additional pinned layer includes AlMn.

12. The magnetic junction of claim **10** wherein the spacer layer is an additional symmetry filter.

13. The magnetic junction of claim **11** wherein the additional symmetry filter and at least one of the free layer and the additional pinned layer have an additional lattice mismatch of less than seven percent.

14. The magnetic junction of claim **13** wherein the additional lattice mismatch is less than four percent.

15. The magnetic junction of claim **12** wherein the additional symmetry filter includes at least one of Ge, GaAs and ZnSe.

16. The magnetic junction of claim **1** wherein at least one of the free layer, the pinned layer, and the additional pinned layer is a synthetic antiferromagnet.

* * * * *